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AC Power Monitoring System Provides Individual Circuit Energy Consumption Data

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Senior Design Project: **AC Power Monitoring System** Provides Individual Circuit Energy Consumption Data

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Research + Scholarship SYMPOSIUM

PROBLEM STATEMENT

How much is your electricity bill?

The U.S. Energy Information Administration collected the following data from Ohio households in 2014.

Average Consumption	901 (kWh)
Average Price	$0.13 ($/kWh)
Average Monthly Bill	$112.63 ($)

However, the real question is where are these "kWhs" being used?

Most consumers do not know the answer to this question. The only piece of feedback people receive on their energy consumption is the electricity bill they pay once a month. If people were more aware of how they used electricity, they would certainly be more energy efficient.

INTRODUCTION

Energy consumption is non-intuitive, and can be difficult to grasp. So first, what is a kilowatt-hour (kWh)?

- A measure of electrical energy equivalent to power consumption of 1,000 watts for one hour.

To calculate the energy consumption of a device, two things need to be known:

- The power being used by the device
- How long the device is turned on

The table below shows the typical energy consumption of some household appliances.

Appliance	Wattage	hrs/day	kWh/month	$/month
Refrigerator	200	24.00	148.80	$18.60
Microwave	1500	0.25	11.63	$1.45
Dishwasher	1200	1.00	37.20	$4.65
Oven	2200	1.00	68.20	$8.53
Toaster	1100	0.10	3.41	$0.43
Keurig	200	0.25	1.55	$0.19
Water Heater	3800	3.00	353.40	$44.18
Washer	2750	2.00	170.50	$21.31
Dryer	2750	2.00	170.50	$21.31
Light Bulb	100	8.00	24.80	$3.10
LCD TV	200	3.00	18.60	$2.33
Laptop	50	8.00	12.40	$1.55
Phone Charger	5	8.00	1.24	$0.16
Ceiling Fan	100	8.00	24.80	$3.10
Curling Iron	90	0.25	0.70	$0.09
Hair Dryer	1500	0.10	4.65	$0.58
Blender	300	0.10	0.93	$0.12

These numbers are all estimates. In order to obtain accurate energy consumption data, every household appliance needs to be monitored at all times. By doing this though, the consumer receives a great amount of feedback on how they are using electricity.

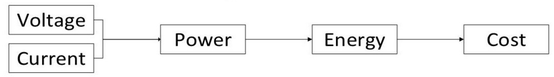
OUR SOLUTION

We have designed, built, tested, and installed an AC Power Monitoring system that is being used to measure power and energy consumption of individual circuits in a circuit breaker panel located in Cedarville's new chemistry lab building. This data is then uploaded to the internet where it is organized and displayed on a mobile application that uses charts and graphs to give the user beneficial information on energy consumption in the lab building.

THEORY AND BACKGROUND

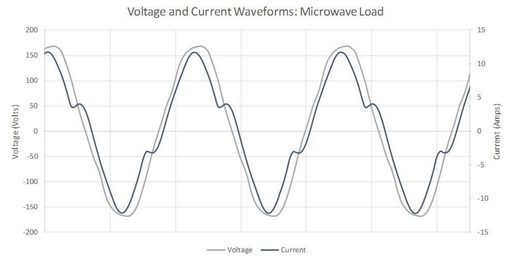
We monitor energy consumption at the most basic level, which comes down to voltage and current on each circuit.

- Voltage: The electric potential in a circuit
- Current: The rate at which electrons flow



Data Acquisition

Voltage is acquired through a simple step-down transformer. This transformer brings the voltage down to a level that is safe for us to monitor, and can be plugged into any normal wall outlet. Current is monitored through current transformers (CTs) that clamp around each wire in a circuit breaker box. They measure current by "transforming" the electromagnetic field the wire produces and turning it into a readable voltage. After our circuitry acquires the data, we have voltage and current waveforms (see below). Power is then a point-by-point multiplication of the two waveforms.



Analog to Digital Conversion

In order to upload the acquired data to the internet, we have to turn these analog waveforms into digital values which is done with a PIC microcontroller.

Data Aggregation and Calculations

All of this digital data is aggregated by a Raspberry Pi which communicates with the PIC via I^2C. The Pi then calculates RMS current, RMS voltage, average power, power factor, and energy consumption over 5 minute intervals. It also packages data to send over Wifi.

Backend and Mobile Application

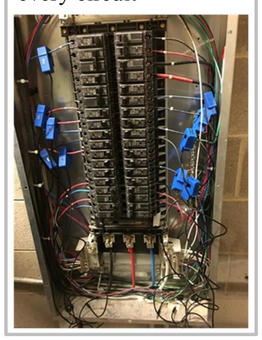
Using a backend as a service (BaaS), we can easily send data from the Pi to the internet via an HTTP POST request. Google provides a BaaS called Firebase that we are using. Firebase allows us to store up to 1 GB of free data, which would last us over a year, and it also serves well as a mobile platform. It has Software Development Kits (SDKs) that work smoothly with mobile application development, so we made our own iOS app as part of the project. The app displays energy consumption data to the user in the form of charts and tables. We show the user real time power rates as well as energy consumption on every circuit in their circuit breaker panel. Data regarding peak channel percentages and cost projections is also available, so the consumer is now aware of their energy consumption habits.

INSTALLATION

1 Clip CT around the outgoing wire

2 Connect CT to the acquisition board

Install CTs on every circuit 3



Download the iOS app and start monitoring 4

THE SYSTEM

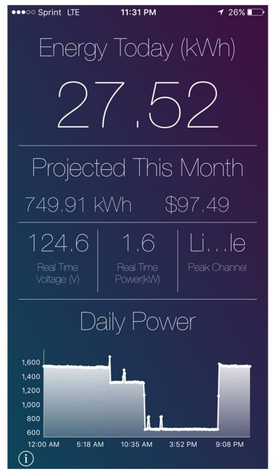
- Completely Non-Intrusive
- Safe To Install
- Monitors Up To 30 Circuits
- Up To 40 Amp Circuits
- Requires Only 2 Outlets
- Commercial Or Residential
- Easily Mountable On Wall
- Wifi Or Ethernet
- Accurate To Within 5%
- iOS Mobile Application

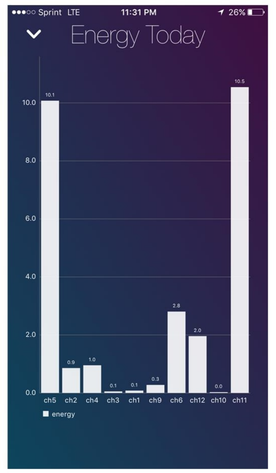
Development Cost	
Engineering Cost	$34,825
Prototype Cost	$439.63
Total	$35,264.63

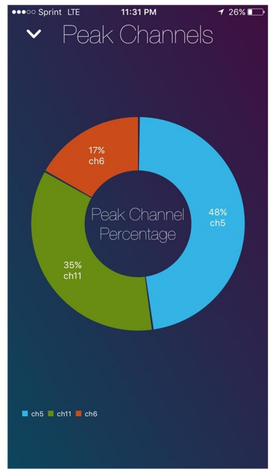
Per Unit Cost	
One Unit	$368.55

RESULTS

We monitored the energy consumption of a circuit breaker panel in Cedarville's Chemistry Lab Building for over a week. The breaker panel contained circuits for an energy management system, an outside light pole, room lights, receptacle outlets, handicap doors, a phone line, and some other loads. We were able to see everything from when the light pole turned on and off each day, to when rooms were in use. Below are some screen shots of our app during the testing period.







FUTURE DEVELOPMENT

This AC Power Monitoring System was meant to be a proof of concept. Now that we have a working system, we hope that future senior design teams can expand on what we have done. The ultimate goal is to be able to install the system in Cedarville's Cafeteria and other lab buildings where there are large dynamic loads. With energy consumption feedback, the cafeteria or any electricity consumer can potentially learn how to be more energy efficient.